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EXPERIMENTAL ADS WITH THORIUM-PLUTONIUM FUEL

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The guaranty of a softy production of atomic energy economically advantageous incineration of Plutonium and the transmutation of long-living radioactive waste are associated now, in a considerable degree, with the electronuclear technology. Thought all basic ADS components have been used for a long time by atomic science and industry, their unification into systems with a power of hundreds and thousandth of MW which can bear long time high temperatures, huge doses of strong-ionizing radiation and intense heat production inside the fuel core, demands a preliminary studing by means of assembles possessing a not great heat power. Such experimental ADSs do not need high-current accelerators and can be installed on the basis of already existing machines with the energy of several hundreds of MeV and microamper proton beams. One of such experimental ADSs with heat power 10-30 kW is designed in Dubna on the basis of 660 MeV proton phasotron and standard Pu-U fuel MOX in the heat-producing rods used in BN-600 reactor [1,2].

At the same time for the countries, like India, that are rich of Thorium, it is interesting to investigate ADSs which use Thorium instead of Uranium, in particular, Pu-Th assemblies. From the pure physical viewpoint the Thorium fuel seems somewhat worse than the Uranium one. Though the number of neutrons created in inelastic collisions of a nucleon with Thorium and Uranium nuclei is almost the same (see Table I), the multiplication of slow neutrons in Thorium targets is significantly less than in uranium ones. For example, the numbers of neutrons created by a proton with the energy E=350 MeV in large blocks of natural Uranium and ^{232}Th are 18 and 12, and respectively 62 and 100 at E= 1 GeV. Energy production in Thorium is approximately as twice smaller than in Uranium [3]. However, in Pu-Th ADS where, in comparison to Uranium nuclei, the fission of Thorium nuclei occurs ten times as rarely, this difference is not very important

For the experimental Pu-Th ADS we chose the construction similar to the Pu-U set-up designed in Dubna. Fig.1 presents the longitudinal section of this set-up. In its active core the standard cassettes with heat producing rods used in reactors with fast neutrons are placed. Each cassette contains 127 such rods with a composition of Plutonium and Thorium dioxides. Every rod is of 50 cm length, 6.9 mm diameter (including a 0.4 mm steel cover) and its fuel density is of 8.64 g/cm^3 [4]. In order to increase the coefficient of neutron multiplication, the steel covers of the cassettes are removed. It is possible since heat power of the system is rather small.

Table I

The calculated average particle multiplicity in inelastic proton -Th and proton-U interactions at the energy E. N_{tot} is the total number of all created, neutral and charged, particles. N_n is the created neutron number

E, GeV		0.2	0.5	0.7	1.0	1.5	2.0
N_{tot}	^{238}U	15	18	23	26	33	39
	^{232}Th	14	17	22	24	31	37
N_n	^{238}U	12	16	19	21	24	27
	^{232}Th	11	14	17	20	23	26

Two variants were considered:

I) with two layers of the fuel cassettes, the relative concentration of dioxides is PuO_2:ThO_2 = 30:70 and the total weight of fuel is 328 kg.

II) With three fuel cassette layers, the relative dioxide concentration is PuO_2:ThO_2 = 24:76 and the total fuel weight 659 kg.

In both cases the presence of 2% of ^{240}Pu is taken into account.

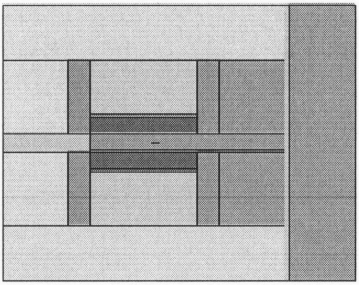

Fig.1. Longitudinal section of the electronuclear set-up. The central lead target of 4 cm radius with 2 mm protection steel cover is surrounded by a channel for air cooling (1 - 2 mm). The fuel core with 2 mm steel cover is inside 30 cm Beryllium reflector and the 50 cm external layer of heavy concrete radiation shielding (its density is of 4.8 g/cm^3). The needle-sharred proton beam enters the target center at a depth of 40 cm. On the opposite end-wall there are two leaden layers of 30 cm width to take-in γ-radiation. The radius of the set-up is about 100 cm, the total length is 180 cm.

The mathematical modelling of ADS has been done by means of the developed at JINR (Dubna) Monte Carlo code CASCADE calculating transport of high- and low-energy particles in heterogeneous multiplication media with a complicated geometry and nuclear contents [5]. The **inelastic** high-energy interactions are calculated on the basis of the cascade-evaporation model taking into account a competition of evaporation and fission of high excited residual (aftercascade) nuclei and created due to fission nuclear splinters.In the region of $E = 10.5$-50 MeV the mechanism of an equilibrium decay of excited compound nuclei created due to the absorption of hadrons by target nuclei. Transport of low-energy neutrons in the region of $E < 10.5$ MeV was traced by means of 26-group constants manifested themselves well in calculations of atomic reactors and radiation shielding [6]. To simplify the calculations the hexahedral fuel core has been approximated with two homogeneous in their contents concentric cylindrical zones the outer one of which includes part of the Beryllium reflector. The number of the sampled event changes from 4000 at $E = 100$ MeV up to 2000 at $E = 1$ GeV.

Table II
(per 1 μA of proton current)

	Pure Th			**Two layers**			**Three layers**		
E, GeV	**K_{eff}**	**N 10^{14}**	**Q KwT**	**K_{eff}**	**N 10^{14}**	**Q KwT**	**K_{eff}**	**N 10^{14}**	**Q KwT**
0.1	0.069	0.052	0.12	0.92	0.12	0.35	0.96	0.29	0.70
0.2	0.059	0.24	0.28	0.93	0.61	1.5	0.96	1.6	3.6
0.35	0.062	0.72	0.58	0.93	0.71	5.0	0.96	4.5	9.2
0.6	0.060	3.1	0.89	0.92	5.9	14	0.95	13	29
0.8	0.065	2.9	1.7	0.92	8.6	20	0.94	22	47
1.0	0.061	3.9	2.2	0.91	12	27	0.94	27	59

The calculated values of neutron multiplication coefficient K_{eff}, the average neutron yield N and the produced heat Q are shown in Table II. E is the bombarding proton energy. For comparison the data for a very big (practically without any neutron leakage) block of pure Thorium are also presented [3].

Table III gives the relative ionization losses $q = Q_{ion}/E$, the energy cost of the one neutron production E/N and the relative value of the energy gain in comparison to one-GeV accelerator $G = g(E)/g(1\ \mathrm{GeV})$, where $g(E) = [Q(E)- E]/E$. As one can see, even for accelerators with the energy of several hundreds MeV and pure Thorium the neutron yield and the produced heat will be enough for carrying out the experiments analogous to the proposed ones for Pu-U ADS [1,7]. Though the most share of primary beam energy is spent in this region for ionization processes, the remaining part provides significant neutron generation and energy production in the process of low-energy fission. At E = 350 MeV in the considered ADS with two and three cassette layers 26 and 73 such fissions occur, at E = 600 MeV these numbers are yet 65 and 190 (per one bombarding proton)

Table III

Parameters of Pu-Th ADS
(per 1 μA of proton current)

	Pure Th			**Two layers**			**Three layers**		
E GeV	**q**	**E/N**	**G**	**q**	**E/N**	**G**	**q**	**E/N**	**G**
0.1	95	21	0.16	95	53	0.096	95	22	0.10
0.2	88	51	0.35	90	21	0.25	89	7.8	0.30
0.35	79	30	0.55	81	11	0.50	81	4.9	0.47
0.6	61	20	0.92	68	6.4	0.88	68	2.8	0.81
0.8	55	17	0.97	60	5.8	0.92	59	2.3	0.99
1.0	49	16	1.00	56	5.1	1.00	55	2.3	1.00

At energies about several hundreds MeV only a few percents of the primary energy is spent for the generation of one neutron. In comparison to E = 1 GeV, the energy gain at ≈ 350 MeV is twice as smaller, however, the decrease can be compensated by increasing the intensity of the proton beam. In the region of several hundreds MeV this can be done much easier than at E=1 GeV. From a technological point of view, it is preferable to use several simultaneously working accelerators, the cost of which is less than the cost of a high-currently one-GeV machine. The accelerating systems with several proton beams are seem to be rather perspective [8,9].

The admixture of ^{240}Pu which, as a rule, is presents in MOX fuel significantly decreases the effectiveness of ADS. Fig.2 shows the change of its parameters depending on the relative isotope concentration η = ^{240}Pu/^{239}Pu. The presented curves are calculated for the Pu-U system [10], however, they are qualitatively applicable for ADS with Thorium fuel too. Already at $\eta \approx 1\%$ one can see a sharp deicers of all ADS parameters, but, as Tables II and III show, by considered concentration ^{239}Pu/^{232}Th they remain quite large.

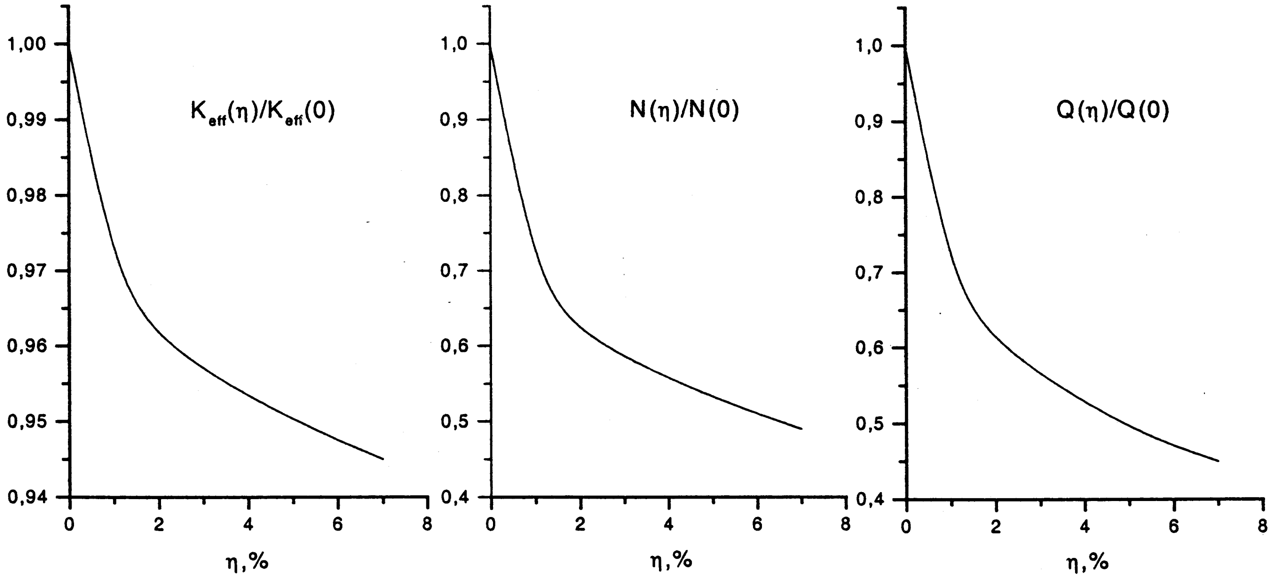

Fig.2. The dependency of the relative quantities $K_{eff}(\eta)/K_{eff}(0)$,$N(\eta).N(0)$ and $Q(\eta)/Q(0)$ on a admixture of isotope ^{240}Pu.

The performed mathematical modelling convinces that Pu-Th ADS can be effective, economically advantageous and the experimental study of such systems can be done on the beams of existing accelerators.
We would like to stress that the use of the already existing proton accelerators with the energy of several hundreds MeV and microamper currents allows one to construct Pu-Th set-ups with a neutron yield of about 10^{13} - 10^{14} and a heat power from one up to several dozens kW which can be used to get data required for the designing of powerful industrial Pu-Th ADS. One must also remark that accelerators with the energy of 300- 600 MeV may be more preferable for ADS than the usually discussed one-GeV machines.

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Барашенков В. С., Пузынин И. В., Кумар В. E2-2001-231
Экспериментальная электроядерная установка
с ториево-плутониевым топливом

Методом моделирования Монте-Карло изучается подкритическая электроядерная установка с топливом MOX, в котором уран заменен торием. Рассмотрены два варианта: с концентрацией диоксидов 24 % $PuO_2 + 76$ % ThO_2, весом топлива MOX $M \cong 660$ кг и с большей концентрацией плутония 30 % $PuO_2 + 70$ % ThO_2, но вдвое меньшим весом топлива $M \cong 328$ кг. При энергии ускоренных протонов $E \cong 100$ МэВ тепловая мощность этих установок составляет около 0,5 кВт/мкА и возрастает до нескольких десятков кВт/мкА при $E = 1$ ГэВ. Существующие протонные ускорители с энергиями несколько сотен МэВ позволяют создавать Th – Pu-установки с выходом нейтронов $\sim 10^{13} - 10^{14}$ и тепловой мощностью до нескольких десятков кВт.

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Barashenkov V. S., Puzynin I. V., Kumar V. E2-2001-231
Experimental ADS with Thorium-Plutonium Fuel

Accelerator driven systems with MOX fuel in which Uranium is substituted by Thorium are studied by means of Monte Carlo modelling. Two types of subcritical set-ups are considered: with dioxide contents of 24 % $PuO_2 + 76$ % ThO_2, the weight of fuel is 660 kg, and with a larger concentration of Plutonium, 30 % $PuO_2 + 70$ % ThO_2, but with a significantly smaller fuel weight 328 kg. At the primary proton energy $E \cong 100$ MeV the heat power of these set-ups is about 0.5 kW for each mkA of the proton current and increases up to several kW/mkA at $E = 1$ GeV. The use of the existing proton accelerators with the energy of several hundreds MeV allows one to construct Pu–Th set-ups with a neutron yield of about $\sim 10^{13} - 10^{14}$ and a heat power from one up to several dozens of kW. Accelerators with the energy of 300–600 MeV may be more preferable for ADS than the usually discussed one-GeV machines.

The investigation has been performed at the Laboratory of Information Technologies, JINR.

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